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PERFORMANCE STUDIES AND REQUIREMENTS FOR PARACHUTES UTILIZED FOR METEOROLOGICAL DATA GATHERING AT ALTITUDES BETWEEN 200,000 AND 100,000 FEET

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INTRODUCTION

Parachutes have been used for a variety of applications for a number of years. Most of these applications have been in the first 30,000- to 40,000-foot-altitude region above the earth's surface. More recently, however, applications have arisen for parachutes at very high altitudes. One of the more prevalent uses has been associated with meteorological rockets. For this use, the parachute is required to lower slowly a meteorological sensor and at the same time act as a wind sensor. Figure 1 is taken from reference 1 where results were presented from an analog computer study concerning the adequacy of a parachute as a wind sensor. The computer study concerned a 15-foot parachute such as is utilized with the ARCAS meteorological rocket system. Figure 1 gives a comparison of experimental and calculated fall rates and shows that at the higher altitudes the assumption of $C_D = 1.2$ (which is an acceptable value for sea-level conditions) and a fully inflated canopy led to descent rates much lower than were being experienced in operational flights. It was obvious then that variations in either the drag coefficient or the canopy area were being experienced in the operational descents. Figure 2 (also from ref. 1) shows variations in canopy area or C_D necessary to simulate on the computer the typical fall rate experienced at Wallops Island. Either the drag coefficient varied from 0.4 to 1.2 over the altitude range of 250,000 to 120,000 feet with complete canopy inflation or the canopy area varied from about 40 percent to complete canopy inflation over the same altitude range with the drag-coefficient value held to a constant value of 1.2 or possibly some combination of the two. It was concluded from the analog computer study that it would be highly desirable to obtain photographs of descents of such parachutes at very high altitudes to clarify questions concerning inflation characteristics of this parachute at high altitudes. This paper presents some results of our efforts at the Langley Research Center to obtain such photographic information.

PARACHUTE AND INSTRUMENTATION

During rocket ascent, the parachute is housed in a container between the forward end of the rocket motor and the nose cone which normally houses an atmospheric sensor and telemeter. Near apogee of the rocket trajectory, the

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parachute and nose cone are separated from the rocket and the parachute and payload descend while sensing atmospheric parameters. For the tests described herein, the flight camera system during descent was as shown in figure 3. The descent configuration is similar to that of the normal meteorological sensing system, except that the telemetry package has been replaced by the camera package viewing up at the canopy. The cameras were modified Air Force N-9 type 16-mm gun cameras and viewing angles of both 120° and 90° were available by using wide-angle lenses. The canopy is fabricated of silk with permeability value of 600 and is partially silverized for radar tracking purposes. Approximately 3 minutes of viewing time was available at 16 frames per second. The rocket launches were conducted at the White Sands Missile Range since higher altitudes can be achieved there than at Wallops Island with this rocket system and since recovery is simpler over land rather than water. In late June and early July 1962, three successful ARCAS rocket launches were conducted with subsequent parachute-camera package recoveries.

DISCUSSION

Figure 4 presents altitude versus the rate of descent for the three White Sands flights. Note the large variation in descent velocities for the three flights. For instance, at 160,000 feet the fall rates varied from 300 feet per second for flight 2 to 900 feet per second for flight 1. All parachutes were identical and the suspended weights were equal. Apogee altitudes were, respectively, 220,000, 223,000, and 208,000 feet for flights 1, 2, and 3. Also shown in figure 4 is the descent rate typical for a good descent with the $4\frac{3}{4}$-pound meteorological payload that is generally utilized at Wallops Island. The suspended weight for the camera packages, however, was 9 pounds.

Sample frames from the films of the three 1962 flights are shown in figure 5. Also shown for comparison is a frame from this configuration, which utilized a 120° viewing-angle lens, for a fully deployed parachute at sea level. This film was obtained by dropping the system from a helicopter. This provided a reference for determining the degree of canopy inflation in the flight films. The canopy is in the center of the frame and the riser line which was attached immediately next to the lens gives a rope-like effect on the film. From the first flight film at 165,000 feet, note the sun reflection on the lens and for this flight a smudge was evident on the lens and was apparently caused by heating of the wrapping tape on the riser line resting against the lens during ascent. Note the canopy size relative to a fully deployed parachute. Close frame-by-frame review of this film indicated that as the parachute started to open, the spin rate imparted by the rocket to the payload which is 15 to 20 revolutions per second apparently caused the suspension lines to twist and thus not allow the canopy to inflate. About a minute later, the suspension lines began to untwist and the parachute proceeded to open. Next is a sample frame from the second flight. In this case, the lens was fogged, probably by the gases from the separation device at ejection. Fortunately the shadow of the riser line, which is the wide dark band across the frame, fell across the lens intermittently as the payload twisted and untwisted, allowing observation of the canopy at certain intervals of time. A twisting motion was observed, but in this case was not severe enough to adversely affect canopy inflation.

Finally, a sample frame is given from the third flight at 165,000 feet. The fully inflated canopy with this camera at low altitude is shown and again was obtained from a helicopter drop. In this case, the 90° lens was utilized; therefore, the canopy image is larger on the frame. In this case two of the suspension lines became draped over the canopy during deployment thereby not allowing full inflation. Some violent fluctuations were noted in this case and probably can be attributed to the nonsymmetrical shape.

Figure 6 shows the variations in canopy projected area with altitude. For flight 1, the film covered about 220,000 to 125,000 feet, and the parachute was about 10 to 20 percent deployed at the high altitude, and remained this way down to 170,000 feet where further opening began. At the end of the film the canopy was a little more than 40 percent inflated. For flight 2, the canopy inflation was essentially complete throughout the period of photography. For flight 3, the canopy was about 50 to 70 percent inflated during the data period. Thus it is seen that the results for the three flights were quite inconsistent. Further discussion of the 1962 flights is given in reference 2.

It is now obvious why the very different fall rates were observed between the three flights. One would immediately conclude that the projected area variations do cause most of the variation in fall rate for operational meteorological flights. However, as will be discussed later, drag-coefficient variations also occur. To improve high-altitude performance of this parachute, it was desirable to first make modifications that would cause more rapid full inflation of the parachute canopy. Since these flights, the manufacturer has made several modifications to the parachute. Probably the most significant of these was the addition of a swivel between the riser line and the payload, tending to eliminate the twisting of the suspension lines.

Figure 7 shows percent of parachute opening with altitude for two successful rocket flights and subsequent recoveries that were made with modified parachutes at White Sands in June 1963. Parachute opening for both flights was as shown by the hashed band on the figure. It is seen that the swivel is somewhat effective, but that some device to assure complete opening immediately after ejection from the rocket would still be helpful. The following are observations from the flight film of the second 1963 flight.

The camera started operating immediately upon ejection of the parachute system from the rocket. For this flight, separation occurred several seconds before apogee. The film started at 231,000 feet and apogee was 5 seconds later at 231,500 feet. Some rather rapid and violent motions were observed, particularly during the first minute of film coverage. The 90° viewing-angle lens was again utilized. The quality of the film this year was much better. The principal improvements include the addition of a lens shade and an improved lens mounting which eliminated the tunnel effect seen in figure 5. Twisting of the suspension lines was noticeable several times throughout the film in spite of the swivel. Evidently the load is so slight much of the time that the swivel does not act. The extra thin base Ektachrome film allowed the use of about 70 feet of film on a regular 50-foot film reel. It was observed that the canopy opened - then closed several times during the first 30,000 feet of descent. The canopy became fully open and remained that way at about 195,000 feet. Total film coverage was on down to about 165,000 feet and the canopy inflation was very stable between 195,000 and 165,000 feet.

Another factor influencing the fall rate of the parachute other than canopy inflation is its stability. As an indication of the stability exhibited by the test parachute at high altitudes, a film was taken by a long-range ground camera that has been installed at Wallops Station. This film was taken when the parachute was at about 150,000 feet, and coning angles of about 35° to 45° from the vertical were observed. The payload in this case was the standard meteorological payload, that is, a telemetry package and bead thermistor temperature sensor. The period of oscillation was seen to be approximately 5 seconds.

The effective drag coefficient which is defined as the drag coefficient in the vertical direction and which directly affects the fall rate is strongly dependent on the stability. Effective drag coefficients were determined from the onboard camera flights, based on the projected canopy area as seen on the flight film. Figure 8 shows values of derived effective drag coefficients with Reynolds number. The equation on the right side of the figure was used to determine C_D. The fall rate ($\dot{H}$) was determined from radar tracking data. The ticks on the curve show the altitudes and at 190K, the Reynolds number was 14,000 and at 40K the R_N was 500,000. Note that effective drag coefficients vary between about 0.6 and 0.8 over the altitude range covered by the film. For the case of the second 1962 flight, since the canopy was nearly completely open during camera coverage, it was assumed that this condition continued to prevail throughout the descent and effective drag coefficients were computed down to 40,000 feet. These values continued to be in the 0.6 to 0.8 region over the entire altitude range covered.

In figure 9 effective drag coefficients computed from radar tracking data of what is believed to be a typical descent of the operational meteorological system have been added. The fall rates shown in figure 4 were utilized and complete inflation of the canopy was assumed. Note the departure in the curves at about 100,000 feet and Reynolds number of 10×10^4. It is believed that this significant increase in effective drag coefficient is associated with a stability phenomenon. Beyers and Thiele (ref. 3) and Clark and McCoy (ref. 4) at White Sands Missile Range have observed noticeable apparent changes in parachute performance at about this same altitude with meteorological payloads by studying the radar signal strength oscillations and transmitted signals from the onboard temperature sensor. Heinrich at the University of Minnesota (ref. 5) has stated that, for some parachutes, a very small difference in suspended weight will determine whether these parachutes exhibit a coning motion or a gliding type of descent. He further states that at a high load figure, that is, the ratio of weight to projected canopy area, the parachute will cone, and at a low load figure the same parachute will glide. Also, it was noted in reference 5 that a gliding parachute exhibits a significantly higher drag coefficient than a coning parachute. With these comments then, the present results may be viewed by extending these observations a little further. The parachute with the heavy weight continues to have about the same effective drag coefficient and probably cones throughout the tracking period, while the parachute with the lighter suspended weight apparently experiences a stability transition from coning to gliding motion, and the effective drag coefficient is increased at the lower altitudes and higher Reynolds numbers. It is possible that the descending system with the heavier weight would also experience this stability transition at some lower altitude; however, data are not available at this time to verify this. Another item to consider is the variation in permeability of the silk material with altitude which also affects stability.

CONCLUDING COMMENTS

In conclusion, it has been demonstrated that the parachute studied does open at altitudes of about 200,000 feet if unfavorable conditions do not exist. The swivel in the system between the payload and suspension lines is apparently an improvement. The high spin rate of the rocket vehicle appears undesirable for satisfactorily deploying parachutes. The next procurement of ARCAS rockets by Pacific Missile Range and NASA will have a lower spin rate. Further experimental studies with cameras covering this complete altitude range appear warranted to investigate further the apparent stability transition. Desirable characteristics for parachutes utilized for meteorological data-gathering purposes are shown in figure 10. Most of them are quite obvious, but may still be warranted here. The altitude range of use would presently be listed as from approximately 260,000 to about 80,000 feet. Since fall rate of a particular system varies exponentially, if no gadgetry is added, satisfactory fall rates at the highest altitudes lead to extremely slow descent rates below 80,000 feet but this would not be too troublesome since these payloads are not necessarily tracked below this point for routine operations. Efforts to have a constant fall rate would be desirable, but, of course, would require a more complicated system. Immediate and positive canopy inflation is highly desirable. The parachute should not glide or sail, since this would cause inaccuracies in wind data derived from tracking its movement. When using parachutes in meteorological rocketry several problems are associated with high fall rates, namely, wind response capability, the response capability of the thermister to the ambient temperature, and compressional heating on the thermister. Two immediate approaches to reduce the fall rate that become obvious are either to simply extend the parachute container and use a larger parachute, or to incorporate new designs that will increase the effective drag coefficient. Of course, a lighter weight electronic package would accomplish the same purpose. The effective drag coefficient can be increased by improving the stability at these altitudes and/or increasing the actual drag coefficient. The parachute should exhibit a good radar target and must be capable structurally and otherwise of deploying satisfactorily in the altitude range of about 150,000 feet to 260,000 feet in the event of poor rocket performance, premature ejection, different launch conditions, etc. Efforts are underway by various groups to perfect several different parachute configurations for high-altitude applications.

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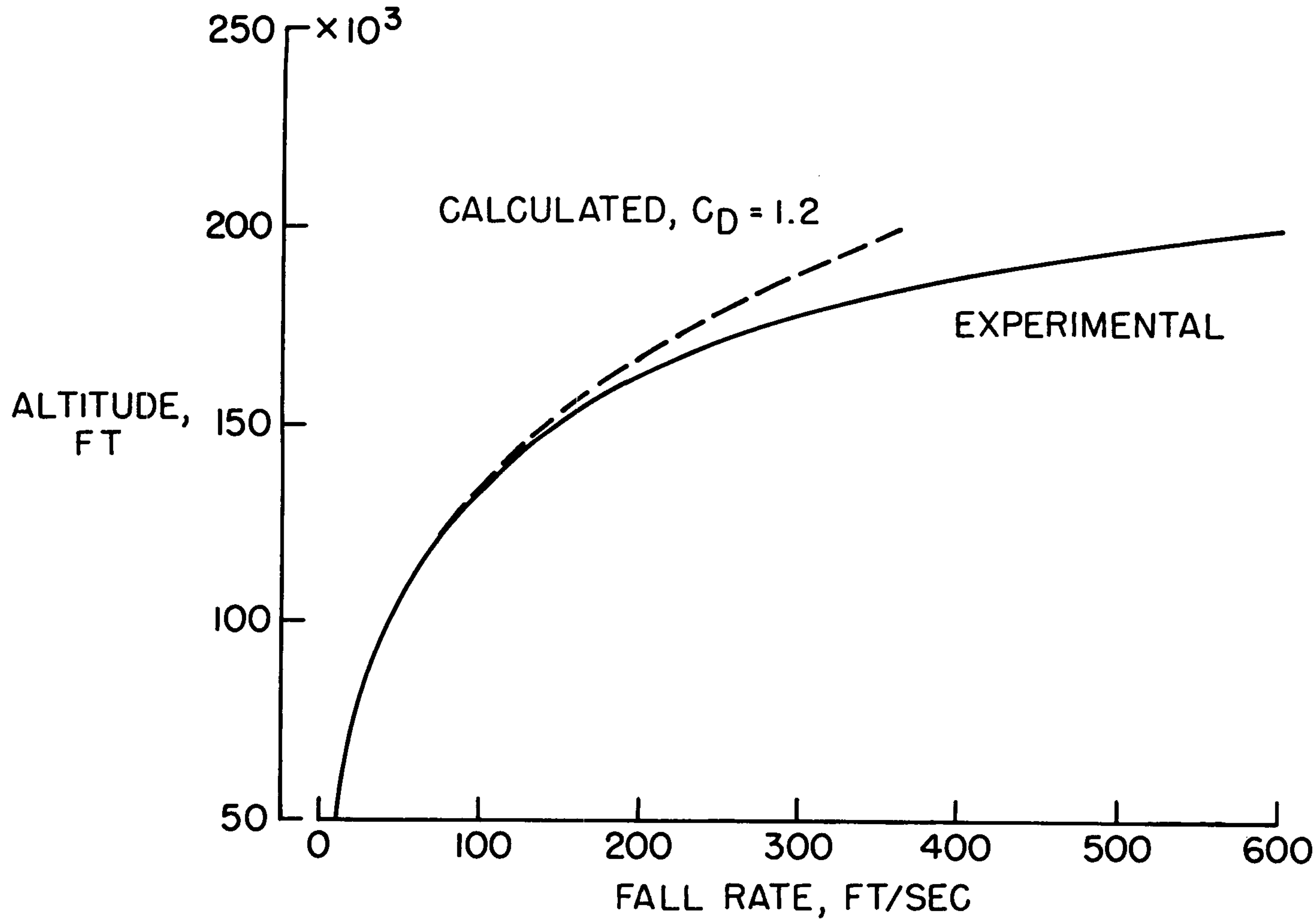

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Figure 1.- Calculated and experimental fall rates.

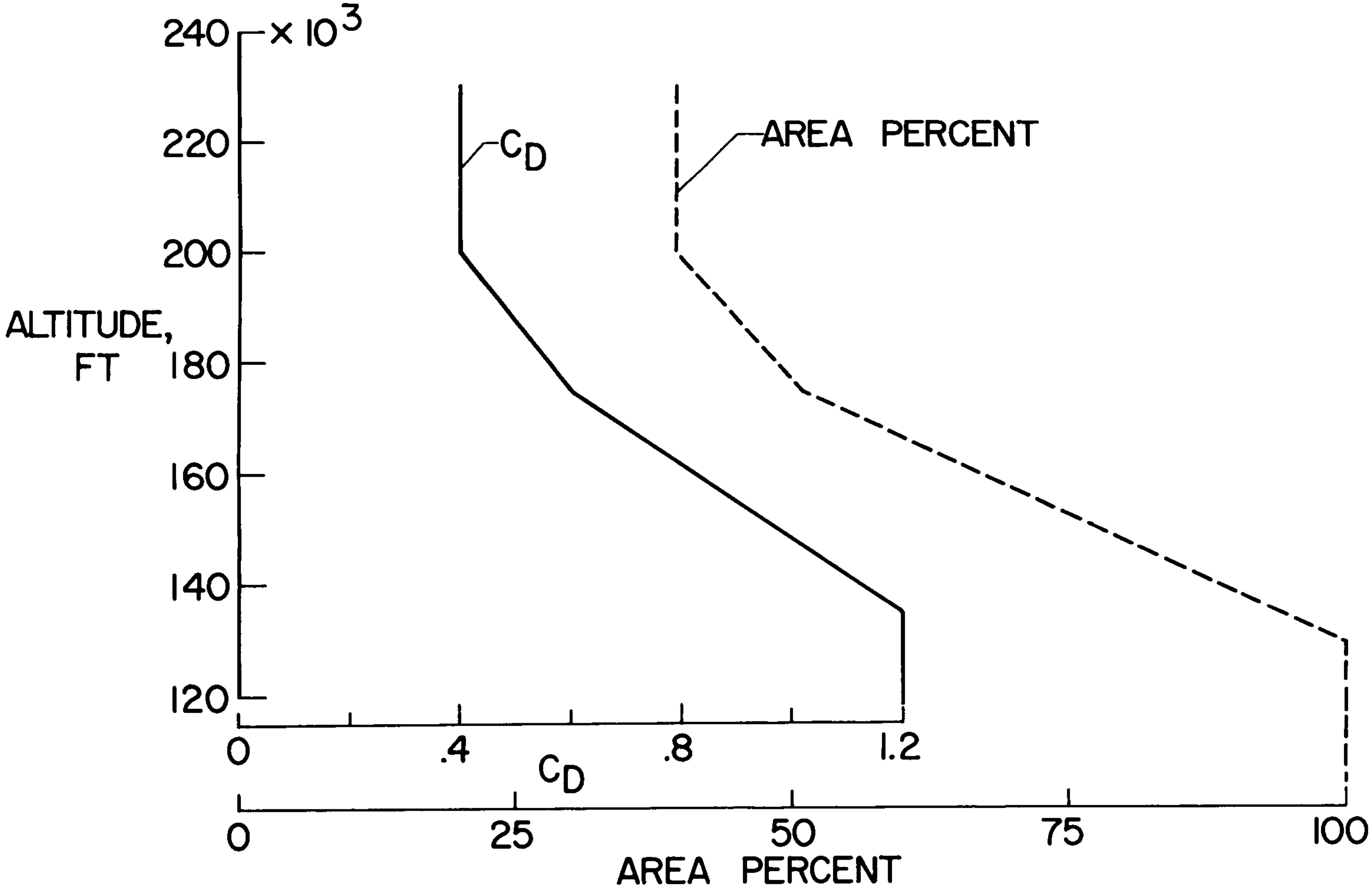

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Figure 2.- Analytical variation of drag coefficient or canopy area necessary to simulate experimental descent rate.

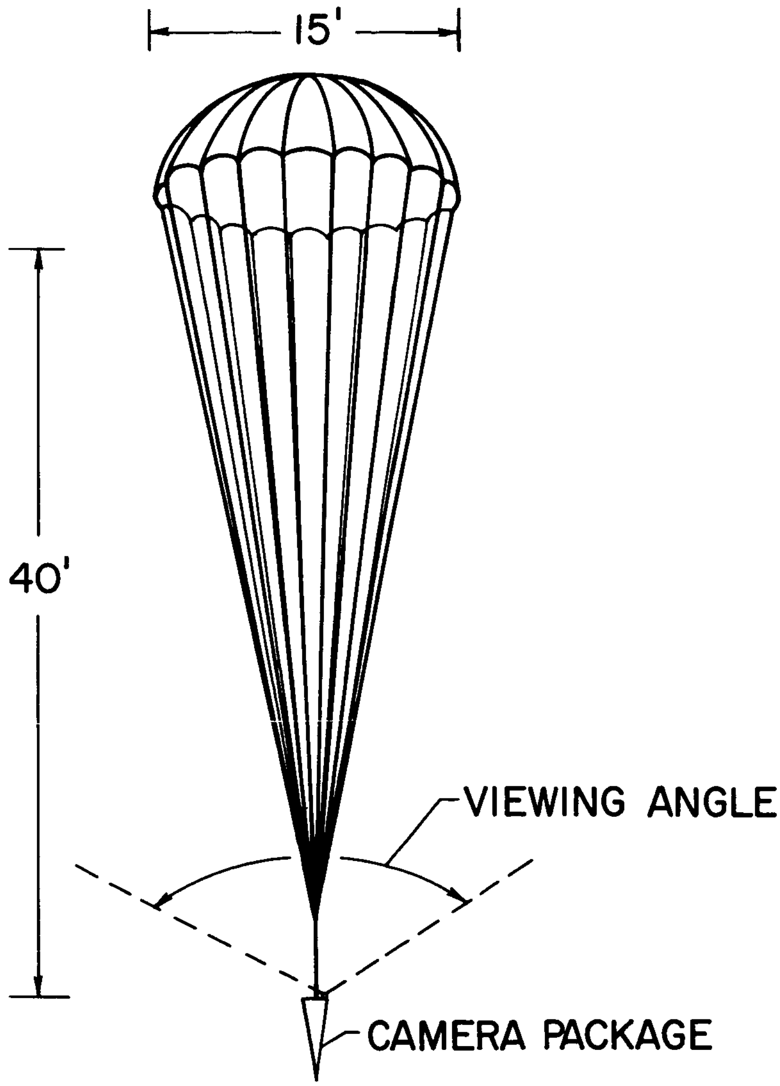

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Figure 3.- Parachute-camera package configuration.

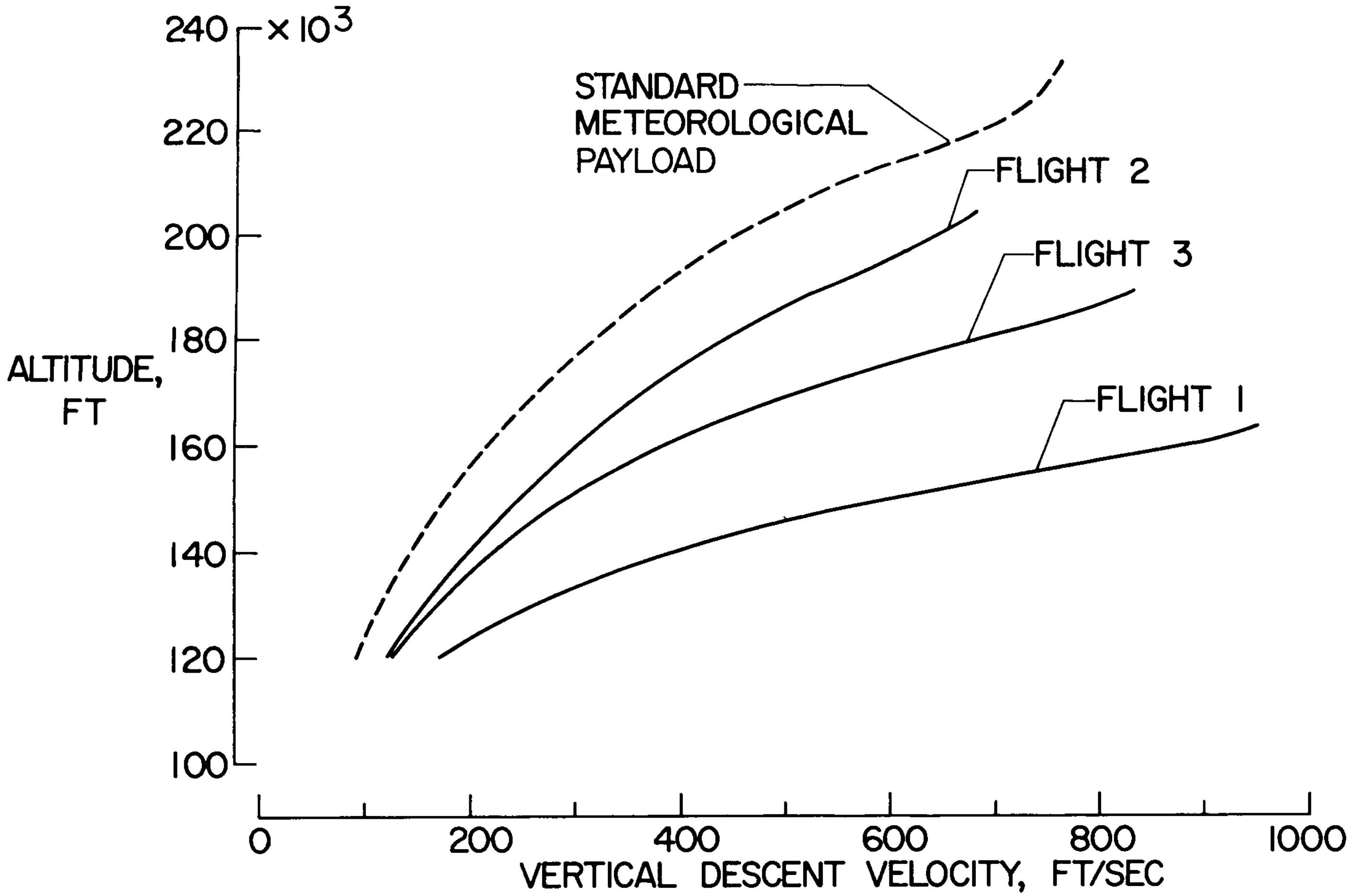

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Figure 4.- Descent velocity variation with altitude (1962).

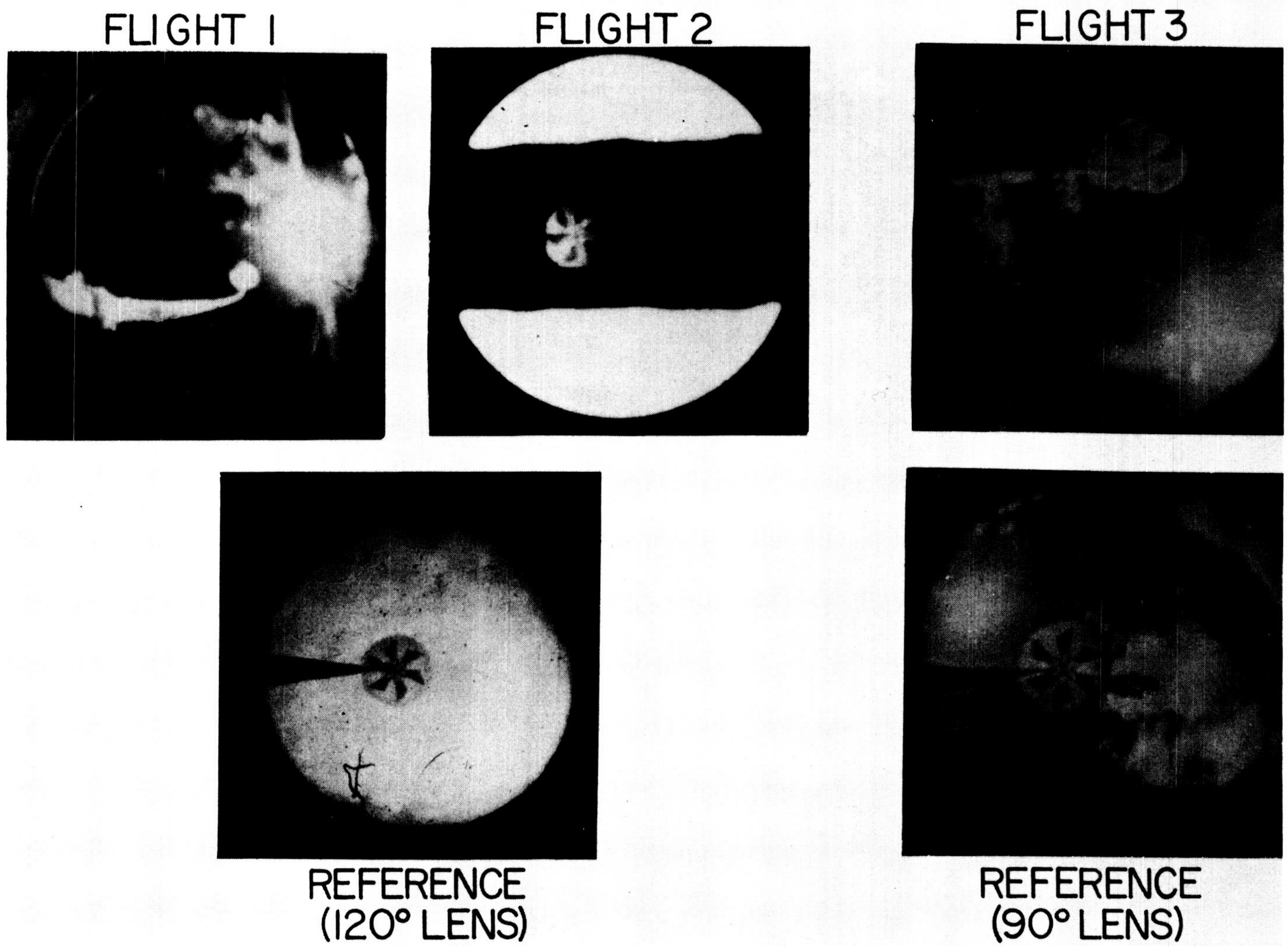

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Figure 5.- Sample frames from flight films (165,000 ft).

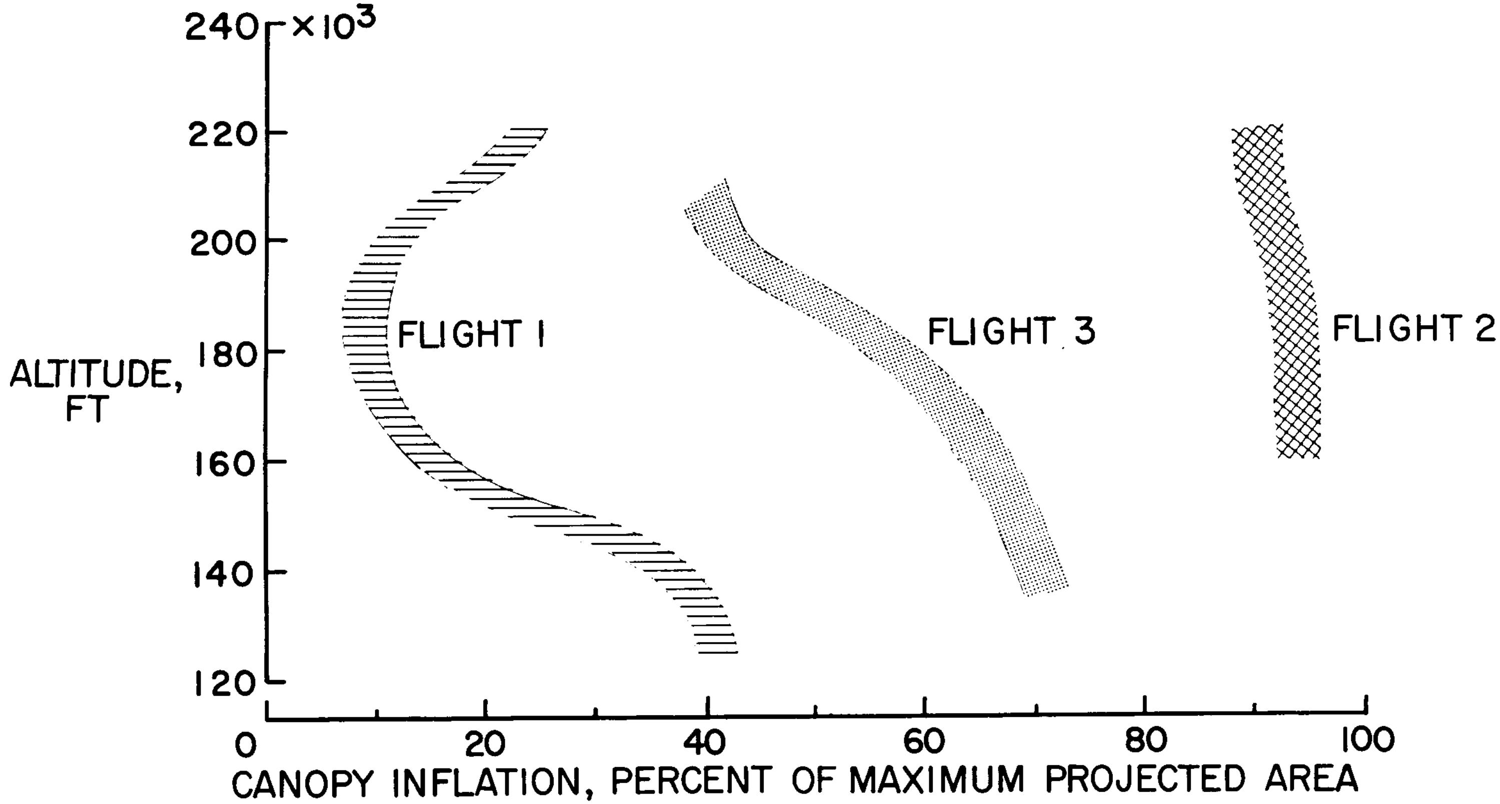

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Figure 6.- Amount of parachute opening for 1962 flights.

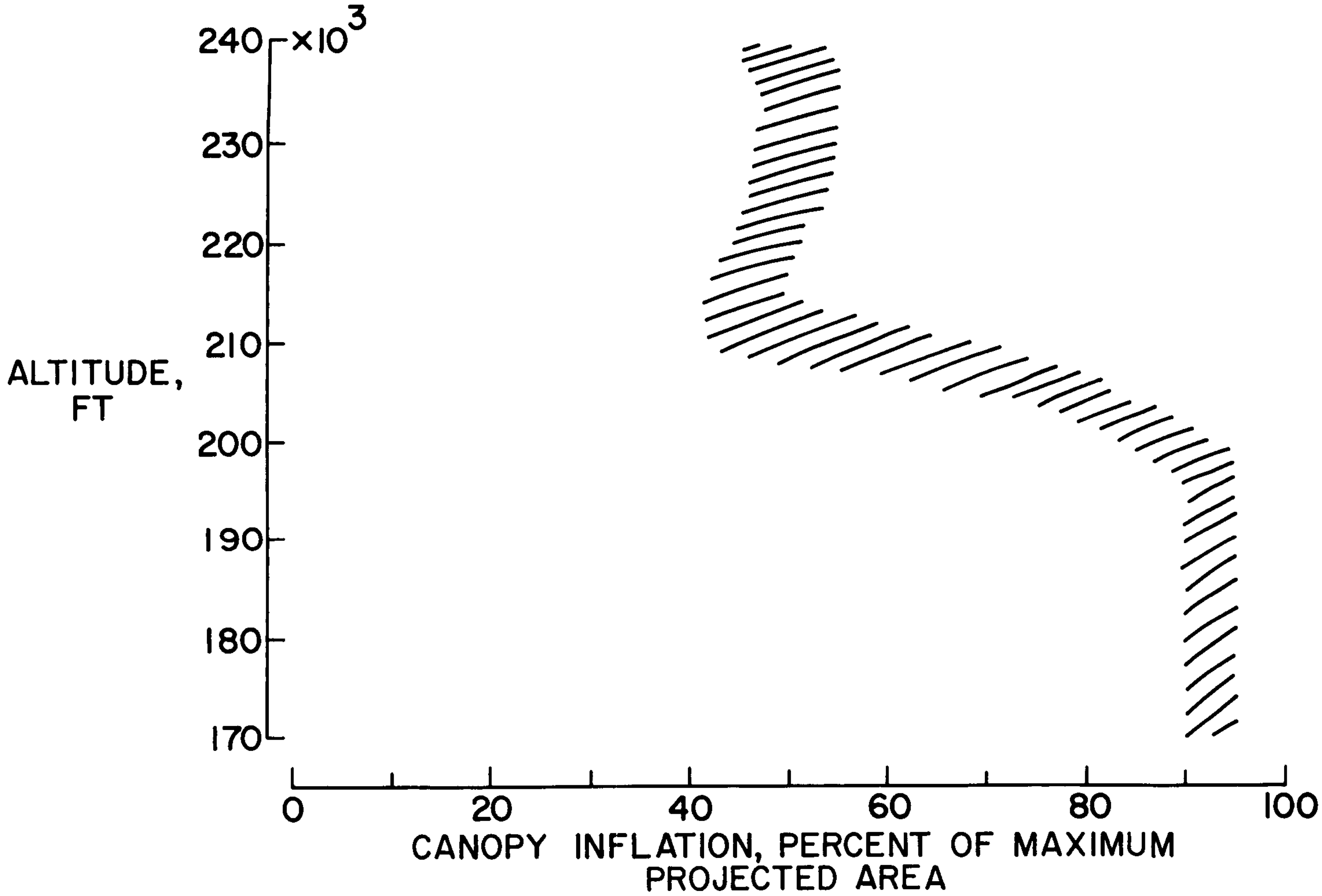

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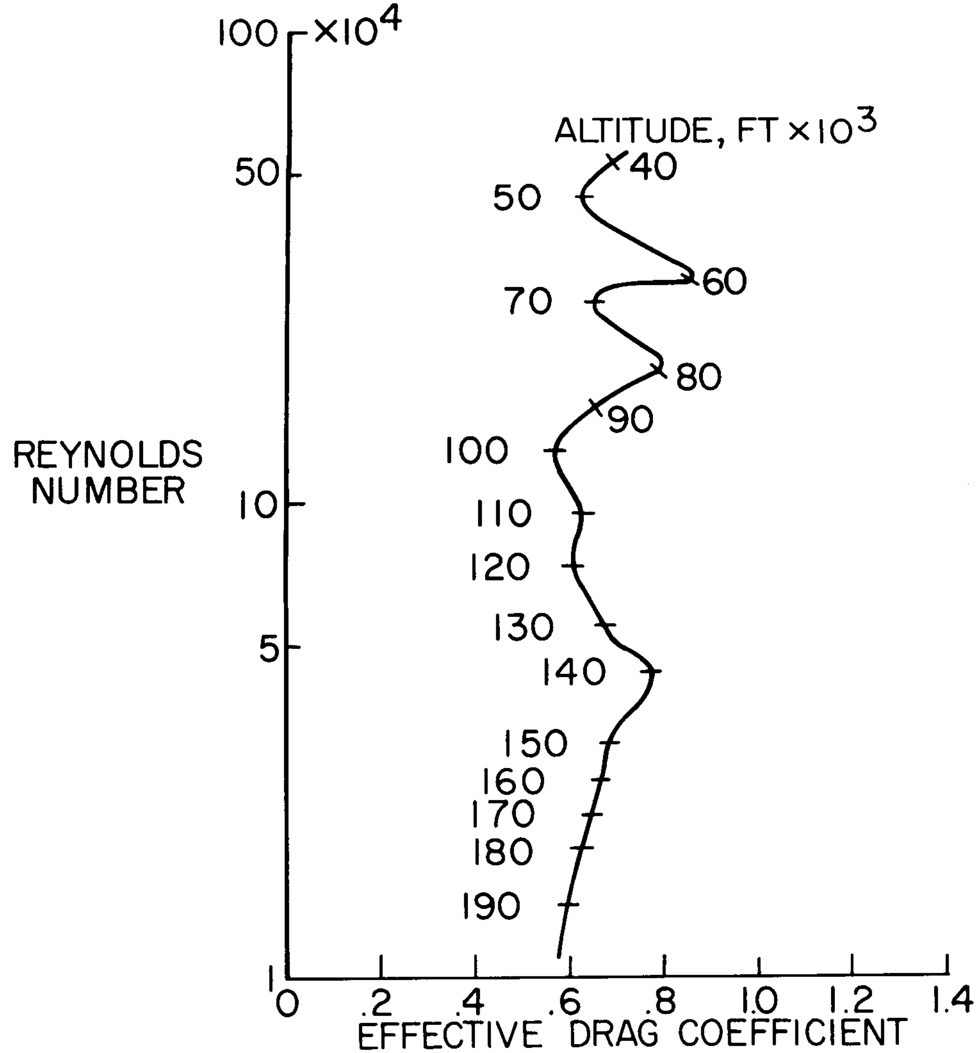
Figure 7.- Amount of parachute opening for 1963 flights.



$$C_D = \frac{\frac{W}{g}(g - \ddot{H})}{\frac{1}{2}\rho \dot{H}^2 S}$$

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Figure 8.- Variation of effective drag coefficient with Reynolds number.

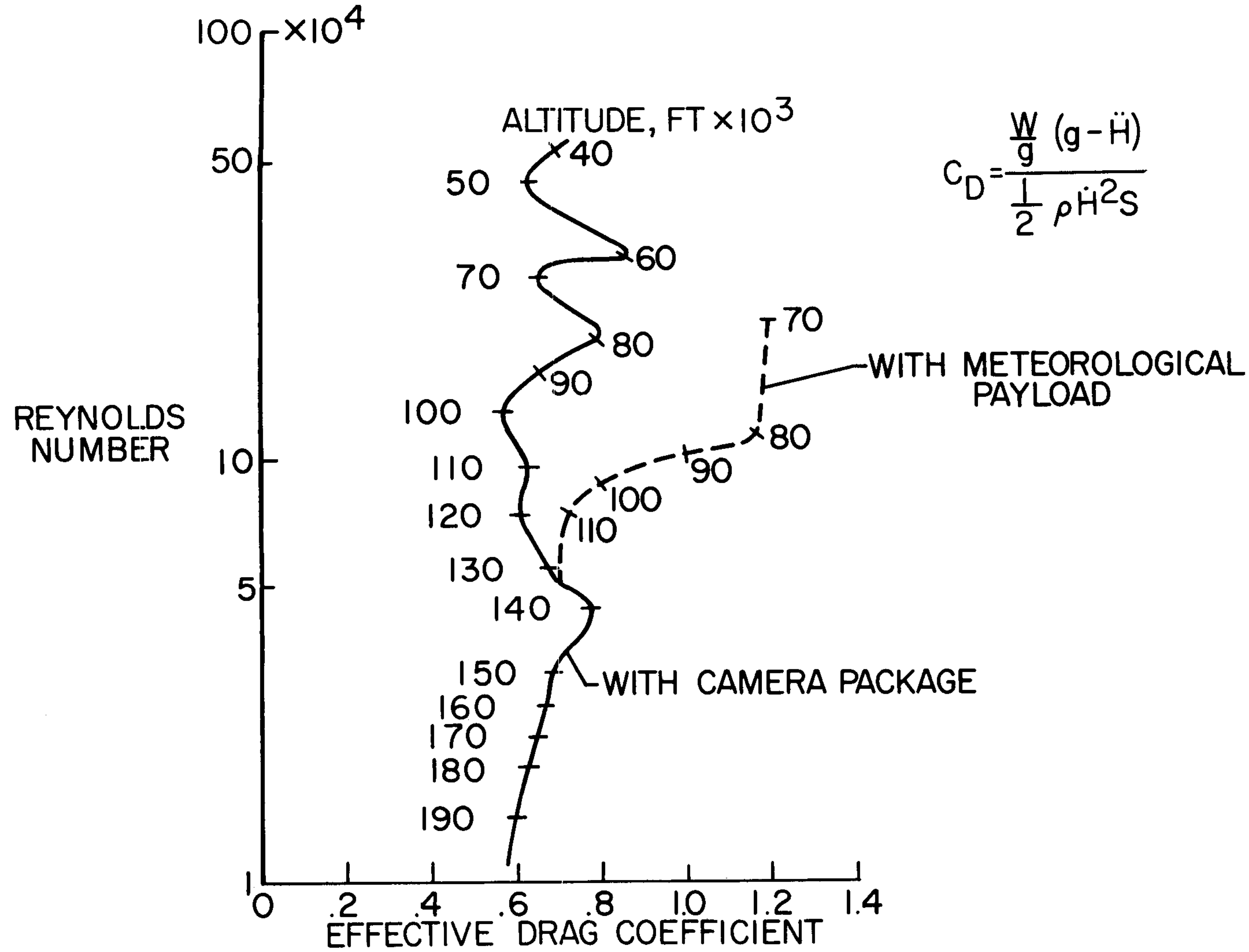

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Figure 9.- Variation of effective drag coefficient with Reynolds number.

- REASONABLE DESCENT RATE
  - STABILITY
  - DRAG COEFFICIENT
- POSITIVE CANOPY INFLATION
- WIND AND TEMPERATURE SENSING CAPABILITY
  - STABILITY
  - DESCENT RATE
- GOOD RADAR TARGET
- STRUCTURALLY SOUND FOR OPENING BETWEEN 150,000 AND 260,000

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Figure 10.- Requirements for high-altitude parachute utilized with meteorological rockets.

NASA-Langley, 1963